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A METHOD FOR CONTROLLING SEDIMENT FROM LOGGING ROADS

by

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INTRODUCTION

Controlling sediment from logging roads on cutover ponderosa pine lands of southwestern Idaho is an acute problem. Such roads usually exist under unfavorable hydrologic conditions; often they are subjected to severe summer storms and spring snowmelt runoff. Furthermore they usually are located on steep slopes where they cut into highly erosive soils derived from acid igneous parent materials (primarily granite). This publication describes a method of protecting intervening slopes, other downhill roads, and stream channels from the damaging effects of sediment that originates primarily from roads higher on the slope. The method was developed from an understanding of the processes involved in erosion from roads and how these processes operate after an area has been logged.

Road construction on steep topography creates instability in the disturbed soil on the slope. But in time a stable soil condition tends to become reestablished on the disturbed areas. During this stabilizing period damage may result; therefore, it is important to encourage and facilitate the stabilization process to attain its maximum development in the shortest possible time without damaging other watershed values.

Secondary logging roads in southwestern Idaho are normally retired from continuous use after logging operations are completed. They are "put-to-bed" with self-cleaning drainage structures and reseeded with a grass mixture. This practice allows road runoff to be channeled from the road surface through open cross drains or ditches, but diverted water flowing onto the loose and highly erodible fill embankment often cuts gullies that are a major sediment source. The higher the fill embankment, the greater the amount of sediment likely to be produced and moved further downslope. As the amount of water in the ditch channel increases, sediment movement likewise increases. Fine sediment particles admixed with heavier particles, are often deposited as streamers of mud over litter or grassed slopes (fig. 1).

Where litter is shallow or the grass cover on the slopes is sparse, energy of the overland flow may be sufficient to erode small gullies and thereby add fresh sediment to the initial flow (fig. 1). While the initial sediment flow is eroding more soil, it drops some of its load upon contact with such slope obstructions as grass, trees, fallen snags, brush clumps, and logging slash. Eventually this flow is dissipated on the protective strip or, if the protective strip is too narrow the flow is carried onto lower roads and

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1/ Forester, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, stationed at Reno, Nevada.

Figure 1.--Sediment dislodgment from an abandoned logging road, Beaver Creek, Boise National Forest.

skidtrails or into a drainage bottom. An important factor that determines whether the protective strip is wide enough to dissipate the sediment load completely is the density of slope obstructions.

This phenomenon of sediment movement occurs at varying degrees of intensity every year on and below abandoned logging roads. It is more pronounced in years when, singly or in combination, unusual climatic and hydrologic events create severe runoff. Conditions conducive to severe erosion are likely to occur shortly after road abandonment and before new plant cover can provide control. Therefore, the treatment method must (a) contain the abnormally severe runoff and not just the year-to-year runoff, (b) contain this runoff if it should occur early in the life of a road while the embankment slope is raw and most vulnerable to erosion, and (c) rely primarily upon cross ditches rather than upon revegetation alone. The method described in this paper includes these features plus the advantage of being adaptable at the time of road layout; it thus insures a more successful and less costly job of post-logging treatment.

DEVELOPMENT OF THE CONTROL METHOD

Information about logging roads used in developing this control method was collected in 1956 from an experimental area on the Little Owl Creek tributary of the Boise River. This site was chosen because the roads had been subjected to unusually severe climatic conditions and runoff the year after they were "put-to-bed" with cross ditches. Because of these conditions, it was believed that the drainage diverted from the road had probably caused very nearly the maximum sediment movement; hence the objects of an exploratory study were to measure sediment movement below the roads and to determine the related controllable site characteristics.[2/]

2/ Haupt, H. F. 1959. Road and slope characteristics affecting sediment movement from logging roads. Jour. Forestry 57: 329-332.

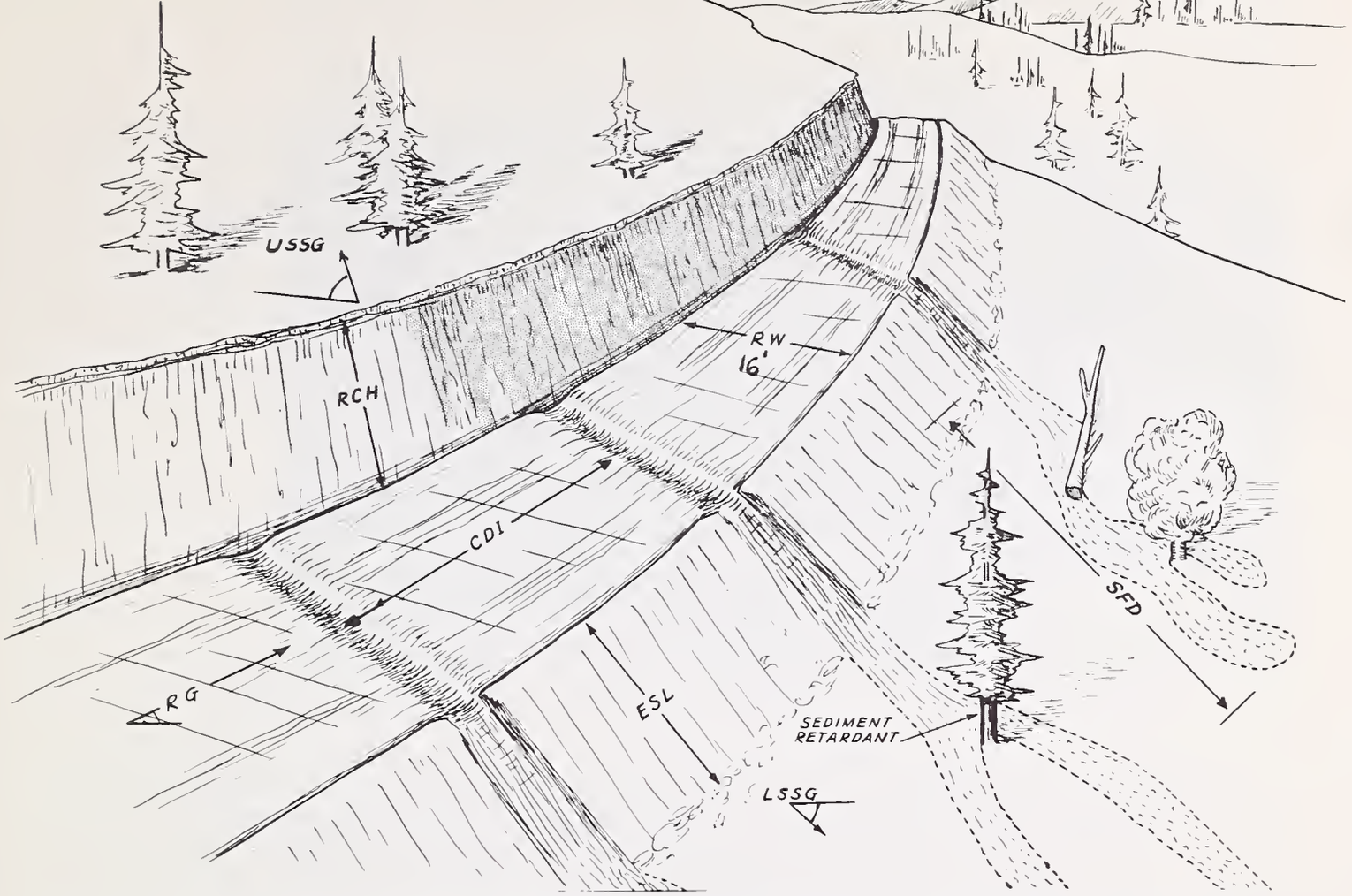


Figure 2.--Sediment flow distance and controllable road and slope characteristics.

Sfd - sediment flow distance

Rw - road width
Cdi - cross ditch interval
Rch - road cut height (vertical)
Rg - road gradient
Esl - embankment slope length (actual)
Lssg - lower side slope gradient

In selecting site characteristics likely to be related to sediment movement, certain physical characteristics of the soil were considered as probably being contributory. However, to expect the road locator to consider these when locating and treating a road was deemed impractical. Instead, road width, cross ditch interval, road cut height, road gradient, embankment slope length, slope obstruction index, and lower side slope gradient were selected because they are amenable to control or alteration by a road planner.

A multiple regression equation was developed relating sediment flow distance (Sfd) in feet to the four significant road and downslope characteristics: slope obstruction index (Soi), cross ditch interval squared $(Cdi)^2$, embankment slope length (Esl), and cross ditch interval times road gradient (Rg). Road width was sufficiently uniform to eliminate it as an important variable. All these characteristics except the slope obstruction index are shown in figure 2. The equation derived was:

$$Sfd = 1.2871(Soi) + .0030(Cdi)^2 + 3.4918(Esl) + .0468(Cdi \cdot Rg) - 66.2395.$$

With proper substitution for the variables, this equation predetermines the distance or width of protective strip needed to dissipate sediment movement that may occur from a road to be built. Another way of using this equation is to have the estimated width of the protective strip (Sfd) given (as is possible after a road has been built), and then transpose the components of the equation so as to solve for any of the four variables. For example, to derive the slope obstruction index, let

$$Soi=\frac{Sfd-.0030(Cdi)^2-3.4918(Esl)-.0468(Cdi*Rg)+66.2395}{1.2871}.$$

Thus, the equation used in either of the above forms, establishes the basis for developing the proposed sediment control method.

Flexibility of the Equation Variables

This method of predicting necessary measures for road location and treatment provides considerable flexibility because two of the variables that affect sediment movement are readily subject to direct control. These are cross ditch interval and slope obstruction index; the latter is susceptible to change by the placement of logging slash. Road gradient can be regulated only at the time the road is located, and then only to a degree because of the need for maintaining grade to gain access into an area where logs will be decked. The fourth variable, embankment slope length, is almost entirely fixed by the gradient of side slope topography.

Cross ditch interval

Cross ditch spacings provided in the several sections of table 2 are 30, 50, 70, 90, 110, and 130 feet. The 30-foot spacing is considered the practical construction minimum when heavy tractor equipment of the D-8 type is to be used. The 130-foot spacing is the maximum considered permissible and is discussed later in this paper.

Slope obstruction index

Slope obstruction index can not be measured directly, as it was in the exploratory study.[3/] Slope obstruction index is calculated by dividing the measured sediment flow distance by the total number of slope obstructions, including a value for the dominant interspace ground cover. In the tables this calculation was modified because the measured Sfd, as such, is nonexistent initially. In its place was substituted the slope distance over which sediment may flow, or the width of the actual protective strip.

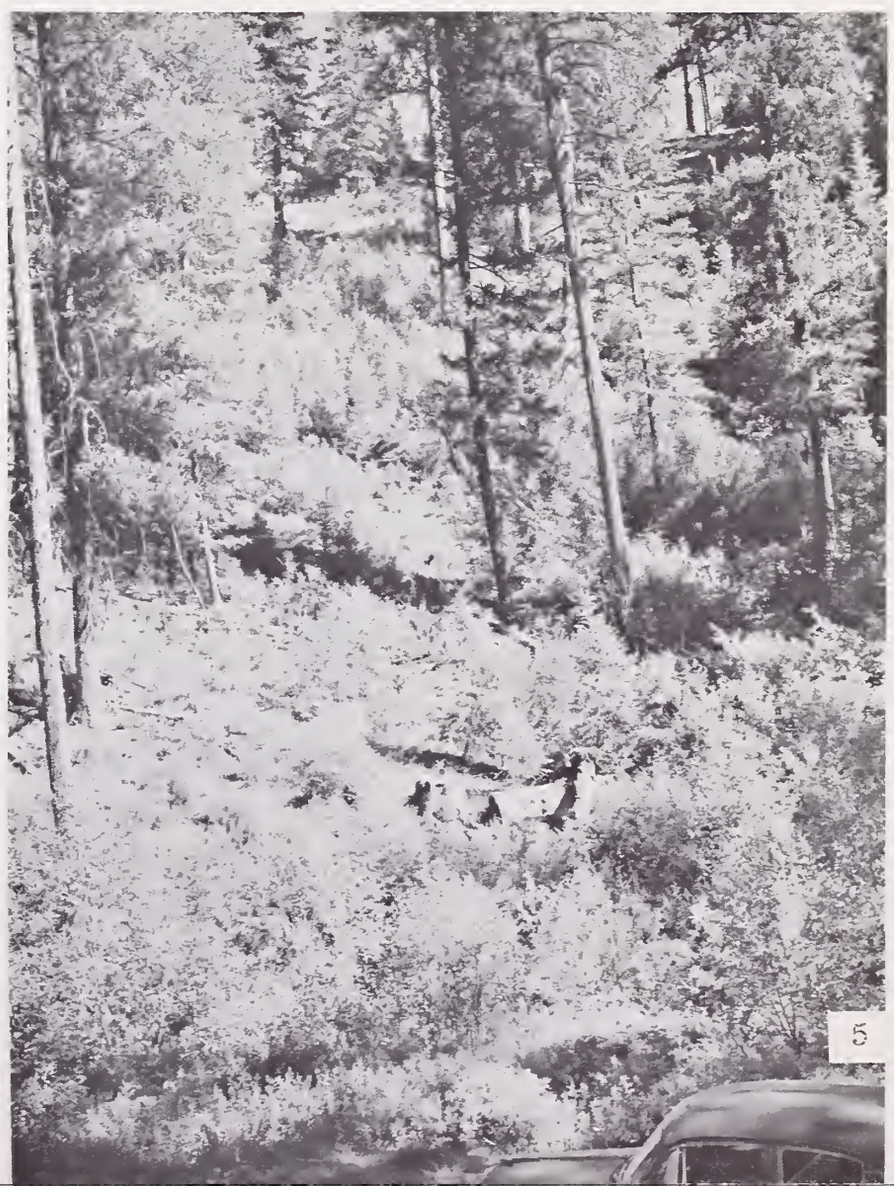
For practical application, the Soi of a slope approximately equals the average spacing (in feet) of major obstructions along the direction of slope. A large index value indicates that the slope obstructions are spaced far apart, as on the open south slope in figure 3A. Conversely, a small index value indicates that the slope retardants are spaced close together as on the

3/ Ibid.

A

Figure 3.--A, an open south-facing slope on Pikes Fork, Boise National Forest. B, a densely covered north-facing slope on Bannock Creek, Boise Basin Experimental Forest, Idaho.

B



densely covered north slope in figure 3B. The closer the obstructions are spaced the more effective they are in slowing the movement of sediment downslope.

On undisturbed side slopes, a natural Soi is commonly not more than 10 on north exposures, 20 on east exposures, 30 on west exposures, and 40 on south exposures. In the following tables, these values represent the "poorest slope obstruction index" found on the respective slope exposures. At the time of road location, the user needs only to identify the slope exposure where the road will be constructed.

When applying erosion control measures after a road has been abandoned, it may be desirable to reduce the Soi on the protective strip. The index is reduced by placing logging slash in the gaps between the natural retardants directly below the cross ditch (fig. 4). Detailed steps for evaluating natural retardants and for placing logging slash are discussed later.

Road gradient

In the several sections of table 2, road gradient is classified in four percentage groups: 1-3, 4-6, 7-9, and 10-12. The user is cautioned against extrapolating beyond 12 percent.

Embankment slope length

The Esl is generally related to the side slope gradient as follows:

Side slope gradient (percent)	20-28	29-37	38-46	47-55	56-64
Embankment slope length (feet)	3-5	6- 8	9-12	13-16	17-20

The user is cautioned against extrapolating beyond the 56-64 percent slope gradients and 17-20 foot Esl classes. In locating roads, the slope of the

Figure 4.--Logging debris effectively retards sediment flow below a haul road.

topography can be measured and the value used in place of embankment slope length, while the latter is used in the road treatment phase.[4/]

APPLICATION OF THE METHOD IN ROAD CONSTRUCTION AND TREATMENT TO PREVENT WATERSHED DAMAGE

Before this method can be adopted for preventing watershed damage, standards of sediment control must be defined. Here it is well to distinguish between a sediment control method and sediment control standards. The method is the means for achieving a goal; here it is a technique for achieving sound erosion control. It cannot establish control standards; these must be set by the forest manager. In actual use of this method, the author recommends what appear to be practical and economical standards for logging roads situated on the granitic soils of southwestern Idaho.

First, however, two assumptions must be made:

1. Logging roads located on these soils are not stable.

2. Some soil movement must be expected, and limited amounts must be tolerated under severe runoff conditions.

The two basic standards for erosion control based on these assumptions are:

1. A distance of 200 feet is established arbitrarily as the maximum distance sediment shall be allowed to move downslope even under a combination of such extreme conditions as: side slope gradient, 56-64 percent; slope obstruction index, 40; road gradient, 10-12 percent; and cross ditch interval, not greater than 130 feet.

2. Not more than one out of six sediment flows (under severe runoff conditions) shall be allowed to extend into a drainage course or onto a lower road.[5/] These two standards define how far and how much sediment movement is permissible below logging roads.

What is the best way to apply the sediment control method to achieve these standards?

First, the road locator must recognize that this method is a field working tool designed to aid him. It is not a substitute for experience and good judgment. Knowing that considerable expense in terms of man-hours and equipment is required to effect erosion control, he must attempt to avoid (a) locating roads along extremely steep slopes, (b) locating new roads close to other roads and drainage courses, (c) building steep gradient roads, (d) building roads wider than 16 feet, (e) crossing draws where side slopes are

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4/ For discussion of the mathematical relationship, refer to appendix I.

5/ The statistical reasoning behind the selection of "one-sixth" is explained in appendix II.

steep, (f) making road junctions where slopes are steep, and (g) locating roads on south slopes (poorer Soi) when other slopes (better Soi) can be used to a greater advantage. The road locator must realize that he can save some of the cost of erosion treatment by exercising good judgment when the road is laid out.

Next to a good job of locating and building roads, close spacing of cross ditches provides the most economical way of preventing movement of embankment material and downslope erosion. This method stresses maximum use of cross ditches. Where narrow protective strips below roads require ditches as close as 130 to 50 feet apart, knowledge of the exact slope obstruction index is not even required. As a safety measure, the Cdi is reduced to compensate for the poorest Soi that may prevail on a given exposure.

However, there is a minimum practical limit (about 30 feet) on the closeness at which ditches can be spaced. This close spacing is associated usually with very narrow protective strips and implies that the slope obstruction index must be considered and probably reduced.

In summary, the following approach is most desirable in applying the control method:

1. Locate roads in the most favorable place for leaving ample protective strips.

2. Use cross ditches liberally as the main deterrent to erosion.

3. Reduce the slope obstruction index only where maximum use of cross ditches alone will not provide satisfactory sediment control.

How to Apply the Control Method Before Road Construction

The main purpose in applying this method before road construction commences is to provide the locator a quick and accurate check against positioning too much of any road too close to a drainage course or lower road. When flagging rights-of-way, the locator should attempt to keep away from streams and other roads at least a minimum distance; this distance depending upon the maximum (or limiting) side slope gradient and road gradient to be encountered on a given slope exposure. To help the road locator, a field guide developed from the main prediction equation (table 1) gives the minimum slope distance to the center line[6/] of the proposed road.

To see how table 1 is used, assume the locator plans to flag a road on a slope having a generally western exposure. By moving from point A, the main access road, and proceeding to point B, the location where logs will be

6/ The distance to center line includes the estimated Sfd, the safety margin of 47 feet added algebraically to the equation components, and the "center line correction" or distance from the toe of the embankment to the center of road (Esl + 8 feet). The poorest slope obstruction spacing common to the exposure under consideration is used in the equation.

Table 1.--Minimum slope distance to center line of the proposed road

Road gradient	Side slope gradient (percent)									
	20-28	29-37	38-46	47-55	56-64	20-28	29-37	38-46	47-55	56-64
Percent	Minimum distance to center line (feet)									
	NORTH					EAST				
1-3	20	40	50	70	90	40	50	70	80	100
4-6	30	40	60	70	90	40	50	70	90	100
7-9	30	50	60	80	90	40	60	70	90	110
10-12	30	50	60	80	100	50	60	80	90	110
	WEST					SOUTH				
1-3	50	60	80	100	110	60	80	90	110	130
4-6	50	70	80	100	120	60	80	100	110	130
7-9	60	70	90	100	120	70	80	100	120	130
10-12	60	70	90	110	120	70	90	100	120	140

decked, he learns either from ground reconnaissance or maps and photos that the proposed road must generally parallel a perennial stream and cross several side draws. He observes that the road gradient will probably not exceed the 7-9 percent class in order to gain point B and also observes that the side slope gradient between points A and B will not exceed the 47-55 percent class. Substituting in table 1 gives a minimum distance to center line of 100 feet. The locator ignores the side draw crossings but attempts to keep the center line at least 100 feet from the perennial stream at any location between points A and B.

However, should the road locator deem it necessary to locate a section of the road less than the desired minimum distance to center line, it is implied that the maximum permissible cross ditch spacing along this critical stretch of road will be 30 feet and that the slope obstruction index will probably have to be reduced by slash. The locator does not record this information in his Erosion Control Action Plan at this time because he must make a final check prior to staking cross ditches.

How to Apply the Control Method After Road Abandonment

For treating roads after cessation of logging operations, the main prediction equation can be readily adapted by permitting the existing distance across the protective strip to equal sediment flow distance and solving for either cross ditch interval or slope obstruction index. The method also affords a way of intensifying the degree of treatment as the slope distance between road and channel decreases. The purpose of intensified treatment is to make doubly certain that the bulk of sediment from roads will not traverse

even the very narrow protective strips. Five intensities of treatment are prescribed depending upon the width of protective strip.

Protective Strips Wider than 200 Feet

Adhering to the erosion control standards discussed previously, roads having protective strips below them wider than 200 feet should not have any two cross ditches spaced farther apart than 130 feet, regardless of side slope gradient, road gradient, or slope exposure (see number 1, paragraph 3, page 7). This does not imply that the erosion control specialist should arbitrarily space ditches 130 feet apart. Obviously, it will be prudent to space ditches closer where a side draw or skidtrail intersects a road or where a road uncovers a perennial seep, to mention only two typical extenuating situations.

Protective Strips Narrower than 200 Feet

Where protective strips below roads are narrower than 200 feet, the erosion control specialist must observe on-the-ground factors before selecting the maximum permissible cross ditch spacing. These factors include slope exposure, embankment slope length, and road gradient. An estimate of the actual width of protective strip should be made.

As an aid to the user, a second field guide was developed from the main prediction equation in the form of tables 2.1-2.7 inclusive. These tables show the maximum permitted cross ditch spacing commensurate with values of the other observed factors.[7/] To illustrate how table 2 is applied, assume that on and below a given stretch of road the following conditions exist: width of protective strip, 71-80 feet; slope exposure, west; embankment slope length, 9-12 feet; and road gradient, 4-6 percent. Refer to table 2.3 and read a maximum permitted ditch spacing of 50 feet, which means that along this stretch of road to be "put-to-bed," no two cross ditches should be staked farther apart than 50 feet. Again, it should be repeated that this maximum spacing requirement does not preclude the possibility of spacing ditches closer where special features of terrain and cover suggest such action.

Protective Strips Narrower than 120 Feet

Where a protective strip below a road is narrower than 120 feet, some combinations of factors, especially on the more erodible south exposures, give a permitted cross ditch spacing of 30 feet (see tables 2.1-2.4 inclusive). Consequently, the protective strips below these 30-foot cross ditches may require a decrease in the slope obstruction index.

7/ The proper cross ditch interval is solved for in the equation by substituting the width of existing protective strip for the Sfd (including the safety margin of 47 feet) and by using the poorest slope obstruction index that may prevail on a given slope exposure.

Table 2.1.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet)											
		0-10				11-20				21-30			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	All				50	30	30	30	70	50	30	30
	6-8					30	30	30	30	50	30	30	30
	9-12	30				30	30	30	30	30	30	30	30
	13-16					30	30	30	30	30	30	30	30
	17-20					30	30	30	30	30	30	30	30
East	3-5	All				All				50	30	30	30
	6-8									30	30	30	30
	9-12	30				30				30	30	30	30
	13-16									30	30	30	30
	17-20									30	30	30	30
West	3-5	All				All				All			
	6-8												
	9-12	30				30				30			
	13-16												
	17-20												
South	3-5	All				All				All			
	6-8												
	9-12	30				30				30			
	13-16												
	17-20												

Table 2.2.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet)											
		31-40				41-50				51-60			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	70	70	50	50	90	70	70	50	110	90	70	70
	6-8	70	50	30	30	70	70	50	30	90	70	70	50
	9-12	30	30	30	30	50	50	30	30	70	50	50	30
	13-16	30	30	30	30	30	30	30	30	50	30	30	30
	17-20	30	30	30	30	30	30	30	30	30	30	30	30
East	3-5	70	50	30	30	70	70	50	30	90	70	70	50
	6-8	30	30	30	30	50	50	30	30	70	50	50	30
	9-12	30	30	30	30	30	30	30	30	50	30	30	30
	13-16	30	30	30	30	30	30	30	30	30	30	30	30
	17-20	30	30	30	30	30	30	30	30	30	30	30	30
West	3-5	All 30				50	50	30	30	70	50	50	30
	6-8					30	30	30	30	50	30	30	30
	9-12					30	30	30	30	30	30	30	30
	13-16					30	30	30	30	30	30	30	30
	17-20					30	30	30	30	30	30	30	30
South	3-5	All 30				All 30				50	30	30	30
	6-8									30	30	30	30
	9-12									30	30	30	30
	13-16									30	30	30	30
	17-20									30	30	30	30

Table 2.3.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet) 61-70				71-80				81-90			
		Road gradient (percent) 1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	130	110	90	70	130	110	90	70	130	130	110	90
	6-8	110	90	70	70	130	110	70	70	130	110	90	70
	9-12	90	70	50	50	110	90	70	50	110	90	70	70
	13-16	70	50	50	30	90	70	50	50	110	70	70	50
	17-20	50	30	30	30	70	50	30	30	70	70	50	50
East	3-5	110	90	70	70	130	110	70	70	130	110	90	70
	6-8	90	70	50	50	110	70	70	50	110	90	70	70
	9-12	70	50	50	30	90	70	50	50	110	70	70	50
	13-16	50	30	30	30	70	50	30	30	70	70	50	50
	17-20	30	30	30	30	50	30	30	30	70	50	30	30
West	3-5	90	70	50	50	110	70	70	50	110	90	70	70
	6-8	70	50	50	30	90	70	50	50	110	70	70	50
	9-12	50	30	30	30	70	50	30	30	70	70	50	50
	13-16	30	30	30	30	30	30	30	30	50	50	30	30
	17-20	30	30	30	30	30	30	30	30	30	30	30	30
South	3-5	70	50	50	30	90	70	50	50	110	70	70	50
	6-8	50	30	30	30	70	50	30	30	70	70	50	50
	9-12	30	30	30	30	30	30	30	30	50	50	30	30
	13-16	30	30	30	30	30	30	30	30	30	30	30	30
	17-20	30	30	30	30	30	30	30	30	30	30	30	30

Table 2.4.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet)											
		91-100				101-110				111-120			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	130	130	110	110	130	130	130	110	130	130	130	130
	6-8	130	130	110	90	130	130	110	90	130	130	130	110
	9-12	130	110	90	70	130	130	110	90	130	130	110	90
	13-16	110	90	70	70	130	110	90	70	130	110	110	70
	17-20	110	70	70	50	110	90	70	70	110	110	90	70
East	3-5	130	130	110	90	130	130	110	90	130	130	130	110
	6-8	130	110	90	70	130	130	110	90	130	130	110	90
	9-12	110	90	70	70	130	110	90	70	130	110	110	70
	13-16	90	70	70	50	110	90	70	70	130	110	90	70
	17-20	70	70	50	30	90	70	70	50	110	90	70	70
West	3-5	130	110	90	70	130	130	110	90	130	130	110	90
	6-8	110	90	70	70	130	110	90	70	130	110	90	70
	9-12	90	70	70	50	110	90	70	70	130	110	90	70
	13-16	70	50	50	30	90	70	50	50	110	90	70	50
	17-20	50	50	30	30	70	50	50	30	90	70	50	50
South	3-5	110	90	70	70	130	110	90	70	130	110	90	70
	6-8	90	70	70	50	110	90	70	70	130	110	70	70
	9-12	70	50	50	30	90	70	50	50	110	90	70	50
	13-16	50	30	30	30	70	50	50	30	90	70	50	50
	17-20	30	30	30	30	50	30	30	30	70	50	50	30

Table 2.5.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet) 121-130				131-140				141-150			
		Road gradient (percent) 1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	130	130	130	130	130	130	130	130	130	130	130	130
	6-8	130	130	130	110	130	130	130	130	130	130	130	130
	9-12	130	130	130	110	130	130	130	110	130	130	130	130
	13-16	130	130	110	90	130	130	130	110	130	130	130	110
	17-20	130	110	90	70	130	130	110	90	130	130	110	110
East	3-5	130	130	130	110	130	130	130	130	130	130	130	130
	6-8	130	130	130	110	130	130	130	110	130	130	130	130
	9-12	130	130	110	90	130	130	130	110	130	130	130	110
	13-16	130	110	90	70	130	130	110	90	130	130	110	110
	17-20	130	110	70	70	130	110	90	70	130	130	110	90
West	3-5	130	130	130	110	130	130	130	110	130	130	130	130
	6-8	130	130	110	90	130	130	110	110	130	130	130	110
	9-12	130	110	90	70	130	130	110	90	130	130	110	110
	13-16	130	110	70	70	130	110	90	70	130	130	110	90
	17-20	110	70	70	50	110	90	70	70	130	110	90	70
South	3-5	130	130	110	90	130	130	110	110	130	130	130	110
	6-8	130	110	90	70	130	130	110	90	130	130	110	110
	9-12	130	110	70	70	130	110	90	70	130	130	110	90
	13-16	110	70	70	50	110	90	70	70	130	110	90	70
	17-20	90	70	50	50	110	70	70	50	110	90	70	70

Table 2.6.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet)											
		151-160				161-170				171-180			
		Road gradient (percent)											
		1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)											
North	3-5	130	130	130	130	A11				A11			
	6-8	130	130	130	130								
	9-12	130	130	130	130	130				130			
	13-16	130	130	130	130								
	17-20	130	130	130	110								
East	3-5	130	130	130	130	130	130	130	130	130	130	130	130
	6-8	130	130	130	130	130	130	130	130	130	130	130	130
	9-12	130	130	130	130	130	130	130	130	130	130	130	130
	13-16	130	130	130	110	130	130	130	110	130	130	130	130
	17-20	130	130	110	90	130	130	130	110	130	130	130	110
West	3-5	130	130	130	130	130	130	130	130	130	130	130	130
	6-8	130	130	130	130	130	130	130	130	130	130	130	130
	9-12	130	130	130	110	130	130	130	110	130	130	130	130
	13-16	130	130	110	90	130	130	130	110	130	130	130	110
	17-20	130	130	110	90	130	130	110	90	130	130	130	110
South	3-5	130	130	130	130	130	130	130	130	130	130	130	130
	6-8	130	130	130	110	130	130	130	110	130	130	130	130
	9-12	130	130	110	90	130	130	130	110	130	130	130	110
	13-16	130	110	110	90	130	130	110	90	130	130	130	110
	17-20	130	110	90	70	130	110	90	70	130	130	110	90

Table 2.7.--Maximum permissible cross ditch interval for roads having protective strips narrower than 200 feet

Slope exposure	Embankment slope length	Width of protective strip (feet) 181-190				191-200			
		Road gradient (percent) 1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
	Feet	Maximum cross ditch interval (feet)							
North	3-5	All				All			
	6-8								
	9-12								
	13-16	130				130			
	17-20								
East	3-5	All				All			
	6-8								
	9-12								
	13-16	130				130			
	17-20								
West	3-5	130	130	130	130	All			
	6-8	130	130	130	130				
	9-12	130	130	130	130				
	13-16	130	130	130	130	130			
	17-20	130	130	130	110				
South	3-5	130	130	130	130	130	130	130	130
	6-8	130	130	130	130	130	130	130	130
	9-12	130	130	130	130	130	130	130	130
	13-16	130	130	130	110	130	130	130	130
	17-20	130	130	110	110	130	130	130	110

To facilitate this, a third field guide (table 3) was developed from the regression equation; it gives the minimum number of slope obstructions needed below each ditch. Factors such as road gradient, embankment slope length, and width of protective strip determine the minimum number of obstructions required.[8/] A slope obstruction can be any major retardant including the dominant interspace ground cover. Each slope obstruction in the following list, except one form of interspace ground cover, has a value of 1, although four kinds of obstructions must exceed a minimum size before rating a value.

Major retardant		Value
standing tree	(3" diam.)	1
down snag	(3" diam. x 6')	1
fallen limb	(3" diam. x 6')	1
logging slash	(3" diam. x 6')	1
rock outcrop		1
tree stump		1
brush clump, usually higher than 2 feet		1
hummock		1
major depression in ground surface		1
Interspace ground cover		
grass or grasslike plants		1
brush stems, scattered and usually not more than 2 feet tall		2

As an example of how table 3 is used, assume that on and below a road requiring ditch spacing of 30 feet, the following conditions exist: width of protective strip, 51-60 feet; embankment slope length, 13-16 feet; road gradient, 4-6 percent; and actual number of slope obstructions, 4 (3 major retardants and 1 for grass cover). Table 3 shows that under this set of conditions the minimum number of 5 slope obstructions is needed. Because 4 obstructions are already present, only one needs to be added (fig. 5). On the other hand, if the actual number of slope obstructions equals or exceeds the computed minimum number, no additional treatment is needed below the cross ditch.

Protective Strips Narrower than 60 Feet

Wherever the protective strip below a road is narrower than 60 feet, some combinations of factors, especially on south exposures, require additional treatment measures such as "contiguous obstructions." Fortunately, such combinations of factors can be held to a minimum if the road locator uses table 1 judiciously at the time of road layout. Nevertheless, there are

8/ This number is derived by solving for Soi. Let the width of protective strip equal the Sfd (includes the safety margin of 47 feet), and then divide the calculated Soi into the width of strip to obtain number of needed obstructions.

Table 3.--Minimum number of slope obstructions needed below cross ditches spaced 30 feet apart

Road gradient	Embankment slope length	Width of protective strip (feet)										
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120
Percent	Feet	Number of slope obstructions											
1-3	3-5	2	2	2	2	2							
	6-8		8	3	2	2	2						
	9-12			13	6	3	3	3	2				
	13-16	Contiguous			18	9	4	4	3	3			
	17-20	obstructions 1/				23	19	5	4	3	3		
4-6	3-5	3	2	2	2	2	2						
	6-8		8	5	3	2	2	2					
	9-12	Contiguous		13	7	4	3	3	2				
	13-16	obstructions				23	5	4	3	3	3		
	17-20						28	7	4	4	3	3	
7-9	3-5	5	3	2	2	2	2						
	6-8			9	3	3	2	2	2				
	9-12				18	5	3	3	3	3			
	13-16	Contiguous				23	10	5	3	3	3		
	17-20	obstructions					28	13	5	4	4	3	
10-12	3-5		8	2	2	2	2	2					
	6-8			13	4	3	3	2	2				
	9-12				18	8	4	3	3	3	3		
	13-16	Contiguous				23	11	5	4	3	3	3	
	17-20	obstructions						22	6	5	4	3	3

1/ Obstructions placed close together perpendicular to the direction of slope with only enough space between to prevent the formation of a "corduroy" effect.

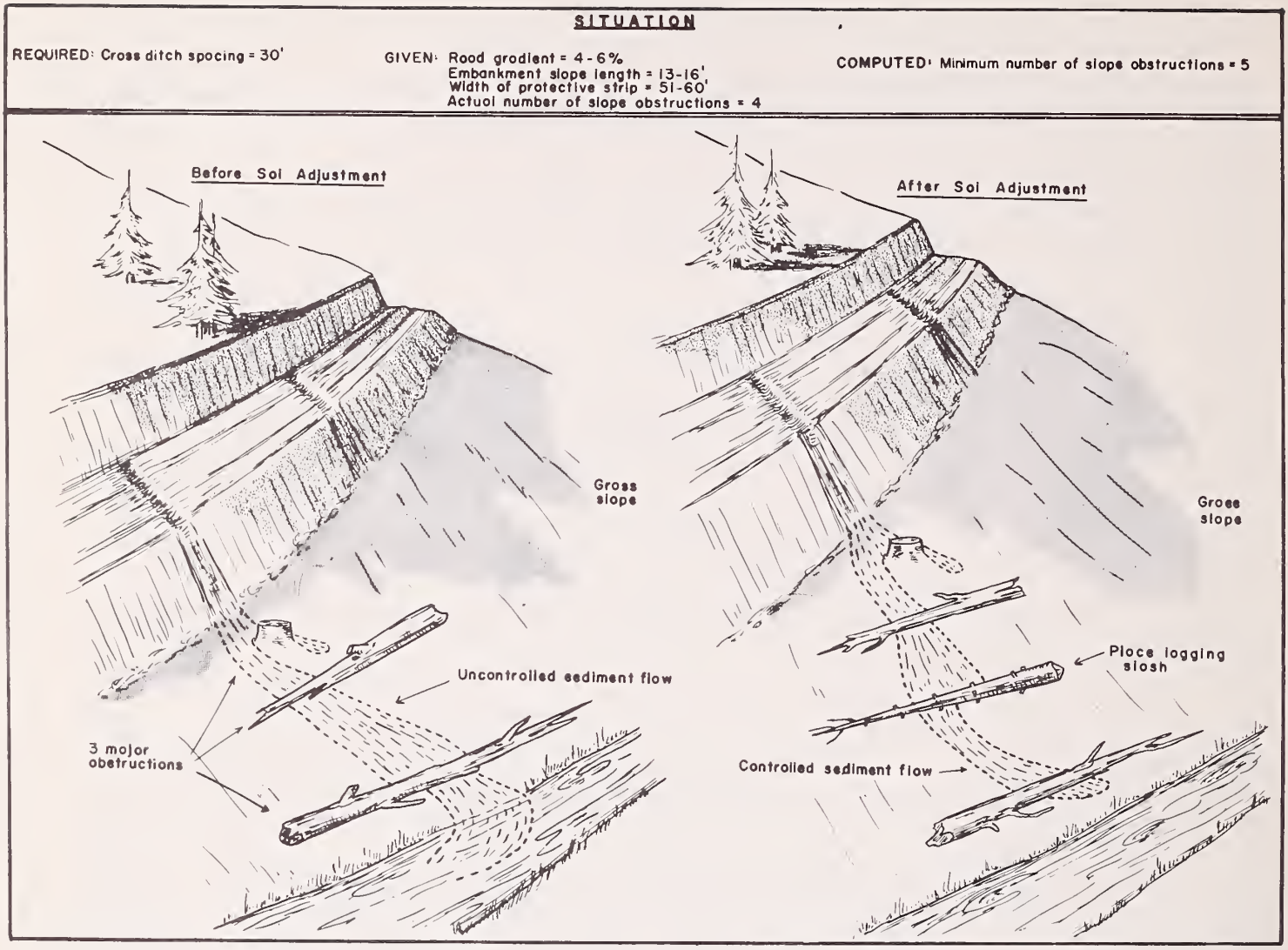
SITUATION
REQUIRED: Cross ditch spacing = 30'
GIVEN: Road gradient = 4-6%
Embankment slope length = 13-16'
Width of protective strip = 51-60'
Actual number of slope obstructions = 4
COMPUTED: Minimum number of slope obstructions = 5
Before Soil Adjustment
After Soil Adjustment
Gross slope
Gross slope
Uncontrolled sediment flow
Place logging slash
3 major obstructions
Controlled sediment flow

Figure 5.--How slope obstruction spacing is reduced by placement of logging debris.

places at stream crossings, at road junctions, or on switchback turns, where protective strips are very narrow, and therefore require additional treatment to handle the potential sediment movement likely to emanate from the road embankment. For instance, the treatment termed "contiguous obstructions" (table 3) calls for the placing of obstructions less than 1 foot apart across the direction of slope below the cross ditch. In using this treatment, care should be taken to prevent building a "corduroy path" for sediment to flow over, but instead to leave a space or crevice between obstructions in which the sediment may lodge.

Protective Strips Approaching Zero Width

Where protective strips approach zero width at the intersection of a road and side draw or stream channel, effective sediment control may be gained by bulldozing a wide "dip" in the road. This will remove much of the road fill material from the direct path of ephemeral or perennial streamflow.

APPENDIX I

Determining embankment slope length

Because embankment slope length cannot be measured when a road is laid out, two additional estimating equations were derived from field data collected in the original study.[9/] In the first regression equation, embankment slope length was designated the dependent variable and was related to several road and slope characteristics thought to be important in the basic design of a road. These included road width, road cut height, upper side slope gradient, and lower side slope gradient (fig. 1); they were tested singly and in various combinations. Of the characteristics tested, the product of road cut height (Rch) and lower side slope gradient (Lssg) was the single variable found to be statistically significant. By computing a regression coefficient for this variable, a prediction equation was derived in which

$$Esl=0.7637+0.0455(Rch \cdot Lssg)$$

with a standard error of estimate of 4.6 feet and 90 percent of the variation accounted for by the interaction of the two characteristics. Road cut height cannot be measured directly until after a road is constructed.

Accordingly, a second equation was developed in which road cut height was related to the slope characteristics, upper side slope gradient (Ussg) and lower side slope gradient. Results showed these two factors, when tested singly and in combination, to be significant and gave the equation:

$$Rch=0.1239\ Ussg+0.0956\ Lssg-0.0015(Ussg \cdot Lssg) \\ -1.3855$$

with a standard error of estimate of 1.0 foot. The three independent variables explain most (96 percent) of the variation in road cut height. Two factors can be measured in the field and substituted directly in the above equations for calculating road cut height and embankment slope length, respectively. The latter value can then be used in the main regression equation. However, unless the proposed road is likely to traverse the crest of a ridge or the base of a well-defined U-shaped canyon, the Ussg and Lssg can be considered equal and can then be referred to as the average side slope gradient.

9/ Haupt, op. cit.

APPENDIX II

Reliability of the Equation Estimates

Before using the main equation, it is essential that the forest manager recognize its reliability. Theoretically, the equation will only forecast close estimates of the actual sediment flow distances that may occur. While one-half of the estimates probably will not be exceeded by actual distances, by the laws of chance an equal number probably will. For greater protection the forest manager should reduce the number that will be exceeded. He can do this by adding to the predicted values "one standard error of estimate" determined by the equation. One standard error of estimate is defined as the standard deviation of individuals around the regression line. For this equation the error of estimate or "safety margin" equals 47 feet. Thus when the safety margin is added to each of the estimated values probably only one out of six of the actual sediment flows that occur below roads will ever exceed the adjusted estimates. With the safety margin added, the protective strip required for trapping sediment will be wider, and the chances that the sediment will not span the protective strip under severe runoff conditions will be increased.